[0016] Fig. 3 is a flowchart detailing the perform supplemental training step of Fig. 2.

DETAILED DESCRIPTION OF THE INVENTION

[0017] The exemplary embodiments of this invention will be described in relation to the application and the invention to an ADSL transceiver environment. However, it should be appreciated that in general, the systems and methods of this invention will work equally well for any multi-carrier communication system including, but not limited to, DSL, VDSL, SDSL, HDSL, HDSL2, or any other discrete multi-tone, discrete wavelet multi-tone DSL or wireless OFDM system.

[0018] As discussed above, the supplemental training according to an exemplary embodiment of this invention commences with a Least Squares solution for the TDQ and improves on the accuracy. Specifically, the number of bits per frame loaded is maximized over the TDQ choice. The function to maximize is the sum of the number of bits that can be loaded in the bins that are used for transmission, and the maximization is over the TDQ setting:

$$\mathrm{Max}_{(a)}\ (\mathrm{SUM}_{(k)}\ (\log_{10}\ (\mathrm{SINR}_k)\ )\ ),$$

where:

- a is the TDQ vector of size Lx1,
- k is the bin index (out of N used bins, while $N<M$ where M is the size of the receiver Fourier Transform), and
- SINR_k is the signal to noise and interference ratio in bin k, expressed as a function of TDQ coefficients, a.

The above is the equivalent of minimizing the following:

$$\min_{(a)}\ (\mathrm{SUM}_{(k)}\ (\ \ln E[\,|\,e_k\,|^2] - \ln E[\,|\,s_k\,|^2]\ )\ ),$$

where:

$E[\,|e_k|^2]$ is the mean square error in bin k,

$E[\,|s_k|^2]$ is the mean square signal in bin k, and

$s_k = u_k H_k A_k a$,

where:

u_k is the medley 4-QAM reference symbol in bin k,

H_k is an estimated (during reverb training) complex channel frequency response at bin k,

A_k is a Fourier basis row vector of length L, having frequency $2\pi k/M$, and

$e_k = s_k - F_k B a$,

where:

F_k is a Fourier basis row vector of length M, having frequency $2\pi k/M$,

B is the received data matrix of size MxL, and

each column of which is the received data frame (before the TDQ block), shifted by one sample as to represent the time passing operation. In the following, the dependence of B, u_k and s_k on frame will sometimes be shown explicitly as B(n), u_k, (n), and $s_k(n)$, where n is the frame index.

[0019] This function is highly nonlinear, and only the portion around the TDQ starting point is modeled by taking the first two terms of the Taylor series expansion. As a result, the function to minimize (over TDQ setting a) is:

$$SUM_{(k)}\,(w_k^e\, E[\,|e_k|^2] - w_k^s\, E[\,|s_k|^2]\,),$$

where the weights are:

$w_k^e = 1/\,E[\,|e_{k,0}|^2]$,

$w_k^s = 1/\,E[\,|s_{k,0}|^2]$, and

$e_{k,0}$ and $s_{k,0}$ are e_k and s_k, evaluated for the initial TDQ setting.

E[.] is evaluated as an average, over medley frames.

After some manipulation, the function to be optimized can be rewritten as:

$$\min_{(a)} (E[a'G_e a - a'G_s a]) = \min_{(a)} \{a'E[G_e]a - a'E[G_s]a\}$$

where:

$G_e = G_{e\_mat}^{+} W_e G_{e\_mat}$, is a matrix of size LxL and where + is the conjugate transpose,

$G_s = G_{s\_mat}^{+} W_s G_{s\_mat}$, is a matrix of size LxL,

$G_{s\_mat} = D_u D_H A$, is a matrix of size NxL,

D_u = diagonal (u) and D_H = diagonal(H), are both matrices of size NxN,

A is a Fourier basis matrix of size NxL, consisting of previously described vectors A_k,

$G_{e\_mat} = G_{s\_mat} - FB$, is a matrix of size NxL,

F is a Fourier basis matrix of size NxM, consisting of previously described vectors F_k,

$W_e = \text{diagonal}(w_k^e)$, $W_s = \text{diagonal}(w_k^s)$, are both matrices of size NxN, and

B is a received data matrix of size MxL, as discussed above.

The directed search for the minimum starts with the initial TDQ vector, a_0, and for each iteration the TDQ is updated:

$$a_i = \text{min eigenvector } \{E[G_e] - E[G_s]\}$$

where $E[G_e] - E[G_s]$has been linearized/localized about a_{i-1} as described above.

[0020] In practice, as discussed hereinafter, the iterations of the supplemental training are continued until arriving at a TDQ with satisfactory performance, or for some other predetermined number of iterations. Note that to obtain the TDQ for a new iteration, the TDQ from the previous iteration is used to estimate the signal, the error, and to obtain the updated matrix $E[G_e] - E[G_s]$.

[0021] Fig. 1 illustrates an exemplary DSL modem 5 according to this invention. In particular, the DSL modem 5 comprises a bit loading module 10, an encoder 20, an Inverse Fast Fourier Transform module 30, a cyclic prefix module 40, an echo canceller 50, a digital-to-analog converter 60, an analog-to-digital converter 70, a time domain equalizer